Methodologies for energy performance assessment based on location data

Space heating models for residential buildings and the influence of urban variables. The case study of residential buildings in Turin (Italy)

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1

Aim

Define energy consumption models at urban scale. Understand how the urban context can influence the buildings' energy consumptions for space heating

- ✓ Analyse the energy sustainability at urban scale, starting from the knowledge of energy consumptions of buildings (Cities on Power, Empowering, *QUADRANTE and EEB - Zero Energy Buildings in Smart Urban District)*
- ✓ Select, through a literature review, urban variables affecting space heating consumptions of residential buildings and
- ✓ Find the relationship to describe how energy consumption can vary with the urban context

2

Energy consumption

$$\left.\frac{kWh}{m^3}\right|_{measured} = \left.\frac{kWh}{m^3}\right|_{building} \pm \left.\frac{kWh}{m^3}\right|_{context}$$

$kWh/m^3_{[building]}$ = f (climate, compactness, period of construction, windows area, systems' efficiency, façades color…)

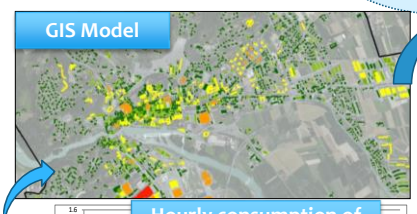
$kWh/m^3_{[context]}$ = f (urban form, materials of outdoor spaces, microclimate variations, …)

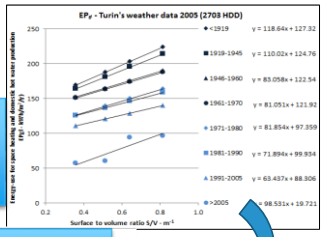
Territorial unit = census section or block of buildings

3

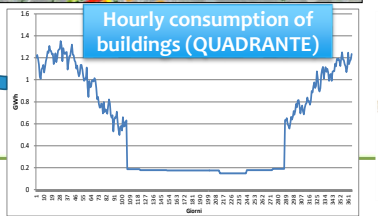
Energy consumption models

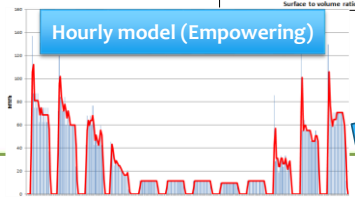
$$\left.\frac{kWh}{m^3}\right|_{measured} = \left.\frac{kWh}{m^3}\right|_{building} \pm \left.\frac{kWh}{m^3}\right|_{context}$$





Simplified model (Cities on Power)





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Territorial scale

Urban scale

Building scale

Top-down model

Bottom-up model

Who?	Data
SEAP Covenant of Mayors Metropolitan City of Turin	Hourly-monthly-yearly climatic data Technical Map of the Metropolitan City of Torino (CTP) Municipal Technical Map for the Cities (CTC) 2011 ISTAT census Thermal and electrical energy consumption data at Municipality scale Energy vectors

Statistical model on municipality scale (with information on the distribution of energy consumption data based on heated volumes or number of users, …)

Comparison of bottom-up and top-down analyses results

Definition of a **simplified energy-use model** for space heating, hot water production and electrical use

Who?	Data
DH company Municipalities Public administrations	Data at building scale : climate, construction period, envelope typologies, system efficiencies, type of users, … Thermal and electrical energy consumption data at building scale Users' behavior, …

Calibration of energy consumption model

Cities on power

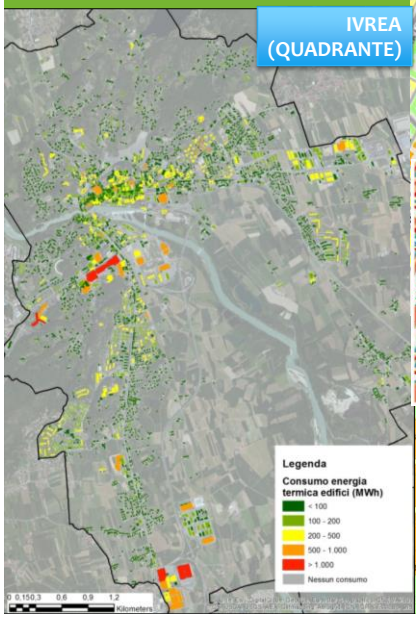
Definition of "correction" factor to consider at urban scale: urban constraints, buildings' energy renovation level, RES distribution, typology of user, …

City	Volume of buildings (at 2005) Mm³	Volume of buildings (2015) Mm³	HDD (UNI 10349: 1994)	HDD (Reference year 2005)	HDD (last 10 years)	Heated volumes (ISTAT 2011)	Correction factor
Turin	160.55	163.36	2617	2703	2449	0.85	1.02

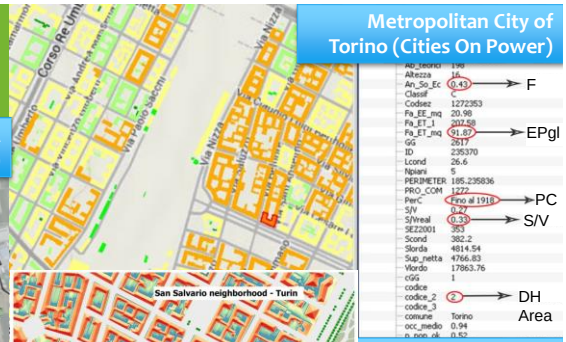
and "demographic" factors because energy-use models describe correctly the energy consumption of heated buildings but they do not fully understand the spatial variability of the heated and unheated spaces and the real extension of the indoor spaces.

Mapping energy consumption

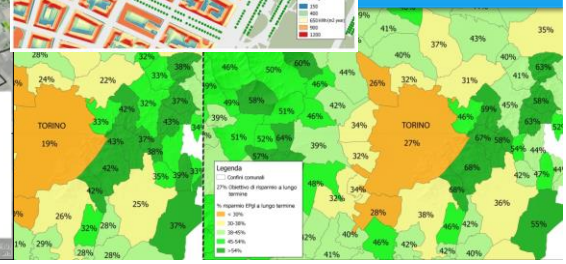
IVREA (QUADRANTE)



Metropolitan City of Torino (Cities On Power)



Energy savings and renewable energy sources potential (Cities On Power)



Cities on power

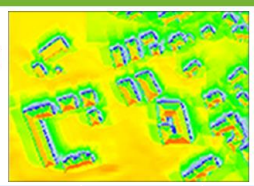
Solar portal

http://energia.sistemapiemonte.it/ittb-torino

ACCESS

Manuale per l'utilizzo

(formato pdf 917 KB)



WEB interface with a cost-benefits analysis of solar RES

Cities	Buildings B (2010)	Apartments A (2010)	A/B	PV potential (MWh)	Electrical Energy-use EE (MWh)	PV/EE (%)
Baldissero T.se	1.103	1.658	1,50	5.007	5.147	97,3
Chieri	4.600	16.137	3,51	27.079	40.857	66,3
Grugliasco	2.255	16.797	7,45	9.777	38.248	25,6
Moncalieri	6.172	25.592	4,15	42.644	67.034	63,6
Nichelino	2.913	20.195	6,93	14.519	48.273	30,1
Pecetto Torinese	1.016	1.746	1,72	10.644	5.720	186,1
Pino Torinese	1.851	3.882	2,10	10.611	12.359	85,9
Settimo Torinese	3.506	20.265	5,78	13.931	47.829	29,1
Torino	35.804	439.251	12,27	228.794	1.091.375	21,0

Energy consumption

$$\left.\frac{kWh}{m^3}\right|_{measured} = \left.\frac{kWh}{m^3}\right|_{building} \pm \left.\frac{kWh}{m^3}\right|_{context}$$

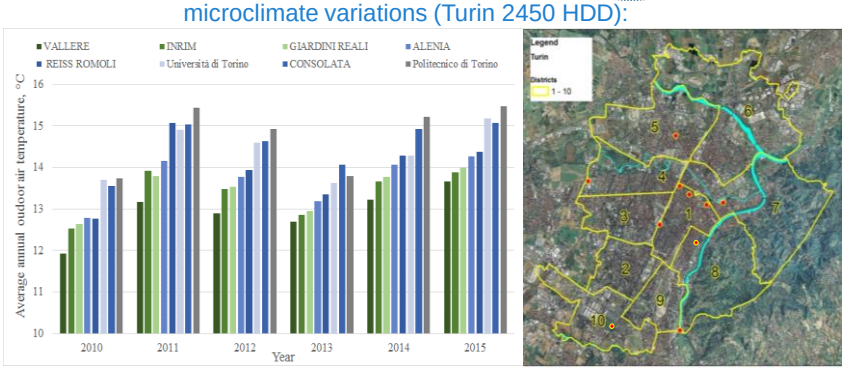
urban form and materials:

Space heating energy consumption and urban form. The case study of residential buildings in Turin (Italy) (SDEWES2016.0441), G. Mutani, A. Gamba, S. Maio, 11th Conference on Sustainable of Energy, Water and Environmental Systems, Lisbon, September 2016

Energy consumption

$$\left.\frac{kWh}{m^3}\right|_{measured} = \left.\frac{kWh}{m^3}\right|_{building} \pm \left.\frac{kWh}{m^3}\right|_{context}$$

microclimate variations (Turin 2450 HDD):

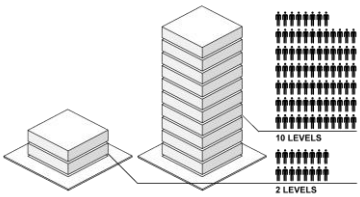


Urban planning for the liveability and thermal comfort of outdoor spaces (SDEWES2016.0442), G. Mutani, 11th Conference on Sustainable of Energy, Water and Environmental Systems, Lisbon, September 2016

Urban context variables

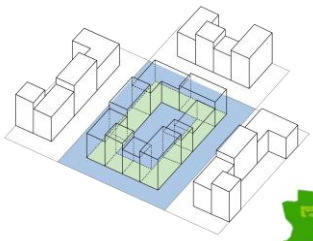
$kWh/m^3_{[CONTEXT]} = f$ (**BD**, **BCR**, H/W, H/Havg, MOS, A)

BD – Building Density [m^3/m^2]

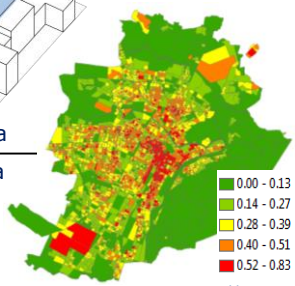


BD = BCR · Building Height

BCR – Building Coverage Ratio [m^2/m^2]



$$BCR = \frac{\text{Built Area}}{\text{Site Area}}$$



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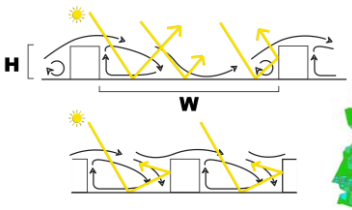
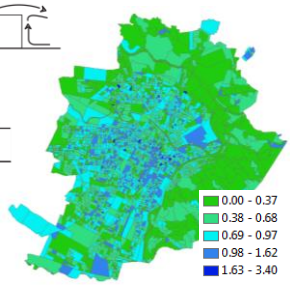
Urban context variables

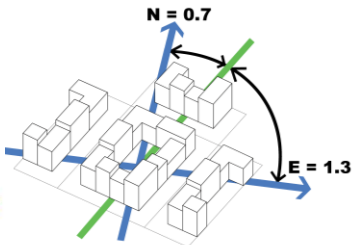
$kWh/m^3_{[CONTEXT]} = f$ (BD, BCR, **H/W**, **MOS**, H/Havg, A)

H/W – Height to Distance or Aspect Ratio [m/m]





MOS – Main Orientation of Streets [-]



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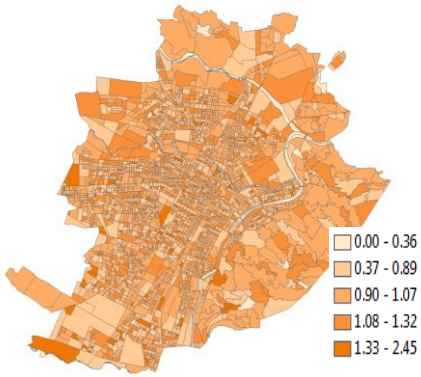
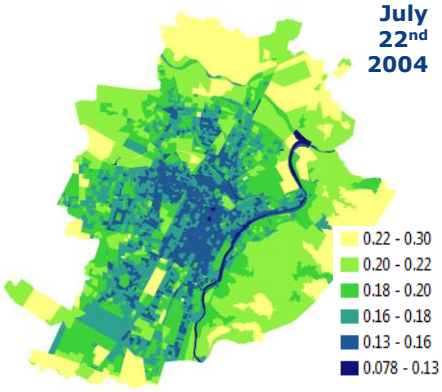
Urban context variables

$kWh/m^3_{[CONTEXT]} = f$ (BCR, BD, H/W, MOS, **H/Havg**, **A**)

H/Havg – building relative Height [m/m]



A - Albedo [-]

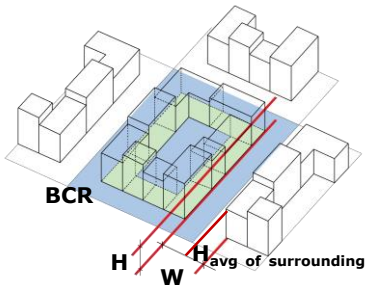


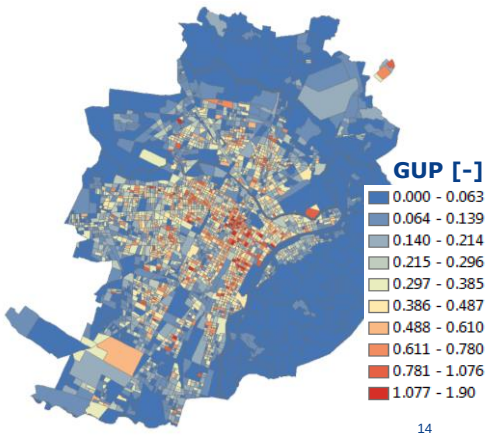
Urban context factors

GUPA = *G*lobal(U · P · A) [-]

Urban morphology factor
U = BCR · H / W = BD / W [-]

solar exPosure factor
P = MOS · H/Havg [-]





$$\frac{kWh}{m^3}\Big|_{measured} = \frac{kWh}{m^3}\Big|_{building} \pm \frac{kWh}{m^3}\Big|_{context}$$

Case study: Turin (IT)

Space heating energy-use of 59 residential buildings
22 census sections

Heating season 2012/2013 = 2348 HDD

Heating season 2013/2014 = 1962 HDD

Weather station ARPA – via della Consolata

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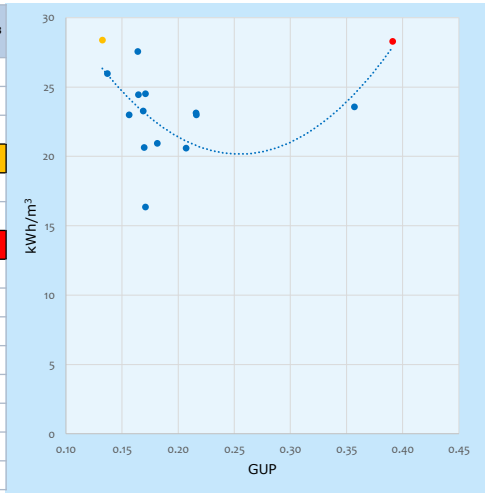
Energy consumption

Census sections	U [-]	P [-]	GUP [-]	kWh/m³
1147	0.187	0.732	0.137	25.96
1149	0.259	0.651	0.169	23.26
1153	0.259	0.698	0.181	20.95
1154	0.140	0.943	0.133	28.40
1155	0.201	0.814	0.164	27.58
1160	0.170	1.005	0.171	16.34
1161	0.467	0.837	0.391	28.29
1162	0.184	0.893	0.164	24.45
1168	0.390	0.914	0.357	23.57
1169	0.239	0.713	0.171	24.52
1175	0.170	0.918	0.156	23.00
1181	0.235	0.722	0.170	20.64
1183	0.265	0.813	0.216	23.13
1188	0.276	0.783	0.216	23.00
1189	0.243	0.851	0.207	20.60



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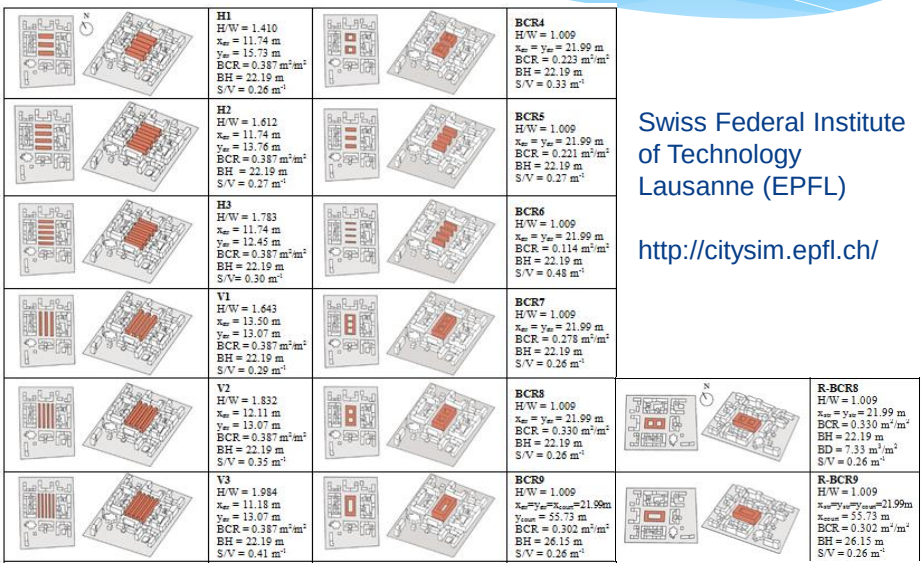
CitySim Simulations



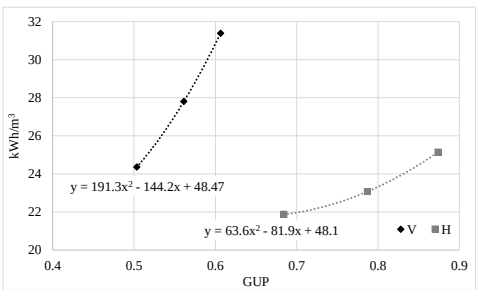
Swiss Federal Institute of Technology Lausanne (EPFL)

http://citysim.epfl.ch/

census parcel 1168

Results

	S/V [m⁻¹]	H/W [-]	MOS [-]	GUP [-]	Energy consumption [kWh/m³]
H1	0.26	1.41	1.2	0.684	21.87
H2	0.27	1.61	1.2	0.787	23.07
H3	0.30	1.78	1.2	0.874	25.13
V1	0.29	1.64	0.8	0.503	24.36
V2	0.35	1.83	0.8	0.561	27.80
V3	0.41	1.98	0.8	0.606	31.37



BCR =

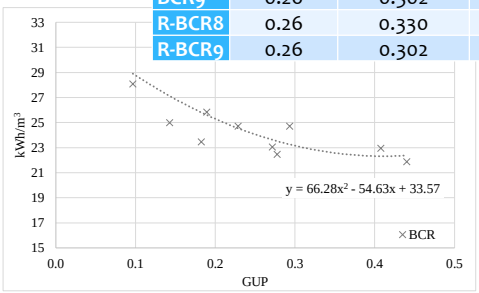
H/W ↑

kWh/m³ ↑

census parcel 1168

Results

	S/V [m^{-1}]	BCR [m^2 /m^2]	MOS [-]	GUP [-]	Energy consumption [kWh/m^3]
BCR1	0.40	0.113	0.8	0.097	28.07
BCR2	0.32	0.168	0.8	0.143	24.99
BCR3	0.29	0.223	0.8	0.183	23.46
BCR4	0.33	0.223	0.8	0.190	25.83
BCR5	0.27	0.221	1.2	0.278	22.45
BCR6	0.48	0.114	1.2	0.145	32.00
BCR7	0.26	0.278	0.8	0.229	24.71
BCR8	0.26	0.330	0.8	0.272	23.04
BCR9	0.26	0.302	0.8	0.294	24.71
R-BCR8	0.26	0.330	1.2	0.408	22.93
R-BCR9	0.26	0.302	1.2	0.440	21.87



H/W =

BCR ↑

kWh/m^3 ↓

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Results

$$U_{optimal} = (BCR = 0.33) \cdot (0.9 < H/W < 1.1)$$

$$P_{optimal} = (H/H_{avg} > 1) \cdot (MOS > 1.15)$$

Solar factor	Urban Morphology factor UM and Heating Energy-use [kWh/m^3]$_{avg}$					
	U < 0.3		0.3 ≤ U ≤ 0.36		U > 0.36	
P < 1.15	BCR1, BCR2 BCR3, BCR4 BCR7	25.41	BCR8 BCR9	23.88	V1 V2 V3	27.84
P ≥ 1.15	BCR5 BCR6	27.23	R-BCR8 R-BCR9	**22.40**	H1, H2 H3	23.36

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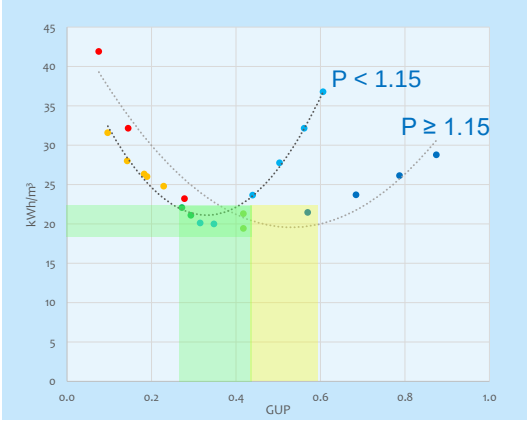
Conclusions

ASPECT RATIO, BUILDING DENSITY and SOLAR EXPOSITION



For Turin, the GUP optimal range is between 0.3 and 0.45 to ensure lowest consumptions.
The presence of an optimal solar exposure allows to obtain acceptable energy consumptions also for higher GUP values.

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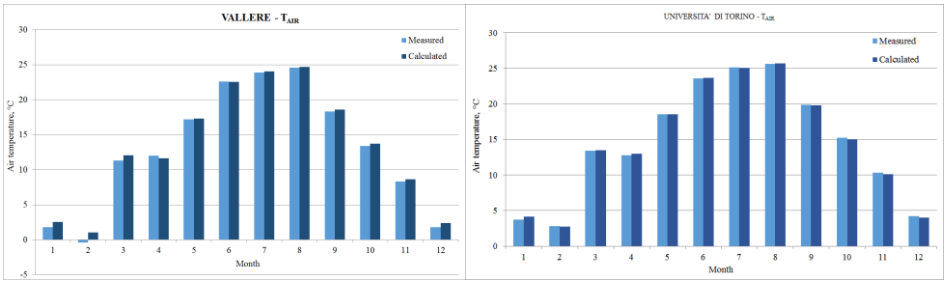
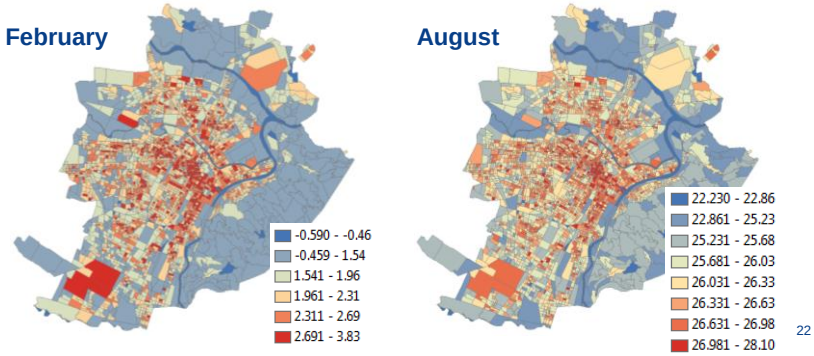


$$T_{air} = 23.05 \cdot G_{mT} + 2.69 \cdot BCR + 0.03 \cdot H/W + 0.65 \cdot MOS + 1.07 \cdot H/H_{avg} - 1.17 \cdot A - 0.6 \cdot H_2O$$



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Smart cities need smart policies

Energy policies must be adapted to local needs and to environment characteristics: there is no one solution strategy!
The important role of urban planning, with urban morphology and solar exposure, in order to design more sustainable cities; the accuracy of methodologies and databases is crucial!

Future improvements:

- Analyse nZEBs with urban variables
- Evaluate different cities and climates
- Introduce the albedo coefficient, the presence of green areas, trees, rivers and lakes
- Analyse also space cooling energy consumptions
- Evaluate thermal comfort and the livability of outdoor spaces

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